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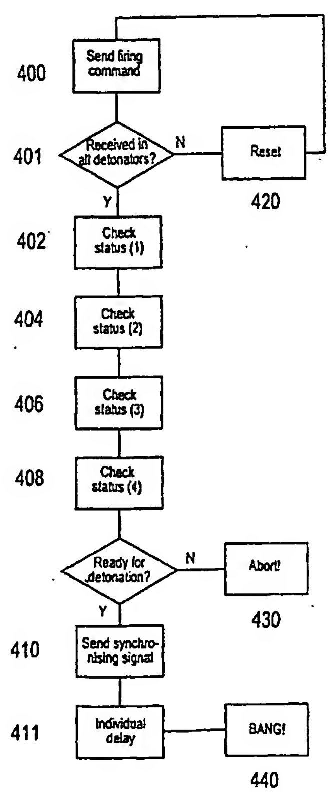

(57) Abstract: A method for firing electronic detonators in an electronic detonator system, said detonators being connected to a control unit via a bus. A firing command or a test firing command is sent from the control unit to the detonators, which start countdown of a delay time stored in each detonator at a synchronising point which is delayed relative to said command. On completion of the countdown, the detonators are caused, in the case of a firing command, to detonate, and in the case of a test firing command, to give a response at the point where they should have detonated if a firing command had been involved. The delayed synchronisation allows checking and control of the detonators after said command has been received. The invention also comprises an analogous method in a system with a plurality of slave control units, to which a plurality of detonators are connected, and a main control unit, the system being controlled at the command of the main control unit.

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ELECTRONIC DETONATOR SYSTEM

Field of the Invention

The present invention relates to an electronic detonator system, more specifically to firing of electronic detonators included in such a detonator system.

Background Art

Detonators in which delay times, activating signals etc. are controlled electronically, are generally placed in the category electronic detonators. Electronic detonators have several significant advantages over conventional, pyrotechnic detonators. The advantages include, above all, the possibility of changing, or "reprogramming", the delay times of the detonators and allowing more exact delay times than in conventional, pyrotechnic detonators. Some systems with electric detonators also allow signalling between the detonators and a control unit.

However, prior-art electronic detonators and electronic detonator systems suffer from certain restrictions and problems.

In prior-art electronic detonator systems, firing of electronic detonators is initiated by means of a firing command which is sent from a control unit. The receipt of the firing command in a detonator starts a non-interruptible countdown of a delay time stored in the detonator, after which time the detonator detonates. A problem of such a method is that at the same time it is necessary to prevent "duds", i.e. detonators that do not detonate although a firing command has been given by the control unit, and unintentional detonations, i.e. firing of a detonator although no firing command has been given by the control unit. When a firing command has been given by the control unit, it is to be hoped that all

detonators function and that all detonators perceive the firing command.

In order to prevent duds, the firing command can be implemented in such manner that it will be easily perceived by the detonators, which, however, can result in also other commands being interpreted as a firing command, with the ensuing unintentional firing.

In an electronic detonator system, where communication between a control unit and a number of electronic detonators occurs electronically, it is also most important that the signalling voltages do not have a level which can result in unintentional firing of the detonators. A low signalling voltage, however, limits the number of detonators which can be connected to one and the same control unit. One reason for the limited number of detonators is that there is always some loss in the signalling, which means that the signalling voltage decreases with the distance from the control unit and thus limits the number of detonators which can be connected to the control unit.

Nevertheless there is in certain detonation operations a need for using a very large number of detonators in one and the same blast.

There is thus a need for new methods and systems for firing electronic detonators, which minimise the risk of duds, eliminate the risk of unintentional firing and besides allow a very large number of detonators in one and the same blast.

Summary of the Invention

An object of the present invention is to provide an electronic detonator system and a method in such a system, allowing reliability and flexibility which essentially obviates the above-mentioned problems of prior-art detonator systems.

A more concrete object of the present invention is to provide a detonator system, and a method in such a

system, which allows functional testing and control of an electronic detonator when this is in a state corresponding to the state immediately prior to detonation. In this description, such a state is referred to as the ready state.

Another concrete object of the present invention is to provide a detonator system, and a method in such a system, which allows use of a very large number of electronic detonators in one and the same blasting operation.

The above objects are achieved by the characteristic features that are defined in the appended claims.

Seen from one aspect, the present invention relates to a method for firing one or more detonators, said method allowing the detonators to be controlled and checked also after they have received the firing command. An advantage of the invention is that the firing command is allowed to have a form which significantly distinguishes from all other commands that are sent to the detonators, whereby the risk of other commands being misinterpreted as being a firing command is practically eliminated. At the same time a check that all detonators have received the firing command is allowed, owing to the possibility of communication with the detonators occurring also after the firing command has been received by the detonators.

According to an embodiment of the present invention, communication occurs to the electronic detonators by means of digital data packets. Since such digital data packets comprise some overhead, they will always contain at least one binary one and at least one binary zero. By ensuring that the firing command consists of a row of identical data bits, preferably binary zeros, a firing command is provided, which significantly differs from said digital data packets. Besides the digital data packets are advantageously designed in such manner that, if the firing command consists of binary zeros, they

comprise as many binary ones as possible, which further emphasises the unique state of the firing command. The number of data bits in the firing command is preferably the same as the number of data bits in the digital data packets.

According to the invention, controlling and checking of the detonators is thus allowed also after they have received the firing command, and especially checking of the fact that all detonators have received the firing command, by communication with the detonators being possible also after the firing command has been received by the detonators. This is accomplished in an advantageous fashion by the firing command setting the detonators in a ready state, which is the state of the detonators immediately prior to detonation, without a final, non-interruptible countdown of a delay time stored in each detonator being started. A non-interruptible countdown of the delay time is instead started at a later synchronising point which is common to the detonators. Up to the synchronising point, communication between a control unit and the detonators can thus occur, thereby allowing control and checking of these. The synchronising point is indicated by means of a synchronising signal which can easily be perceived by the detonators. Consequently the present invention makes it possible to accomplish firing of electronic detonators, whereby the risk of duds as well as unintentional firing of a detonator is essentially eliminated while at the same time the detonators can be checked when they have received the firing command and are in the ready state, i.e. an armed and fully charged state.

The signal which is to be interpreted by the detonators as a synchronising signal can be preprogrammed in the system, or alternatively be indicated by the firing command.

An additional advantage of such a firing method is that the blast can be aborted if it is discovered that

the detonator is in an incorrect ready state, or if a detonator has, for instance, not perceived the previously given firing command and thus runs the risk of being a dud.

In some applications, it may also be advantageous that the time between the sending of the firing command from the control unit and the sending of the synchronising signal is used to send additional firing commands. In this way, the risk of duds is minimised to be practically zero, since the detonators will most probably perceive at least one of the these firing commands. More than one firing command may, however, result in the detonators detonating at an incorrect time, relative to the stored delay times, and therefore a careful consideration should be made before a function of this type is implemented in the system. An electronic detonator system according to the present invention is arranged precisely to prevent duds, and additional firing commands as mentioned above will probably not be necessary. However, rules and regulations in some countries may require precisely such a reiteration of the firing command.

Seen from another aspect, the present invention allows that the system comprises a plurality of slave control units, with the associated detonators, which are connected to a main control unit, from which main control unit the main control of the system is performed. Each slave control unit ensures that the detonators which are connected thereto function according to the commands given by the main control unit.

In that case the detonators are controlled by a main control unit, from which commands and enquiries to the detonators are issued. The basic principle of the present invention allows a number of slave control units to be connected to the main control unit. Each of these slave control units controls a set of electronic detonators at the command of the main control unit.

A delayed firing of the detonators, according to the present invention, thus allows a detonator system with a plurality of blasting machines, i.e. a plurality of coordinated sets of detonators each having a bus to a blasting machine of its own. A firing command can be given to all detonators, after which each blasting machine checks that the detonators associated with this blasting machine are ready to be fired. When all blasting machines indicate that each set of detonators is ready to be fired, an activating command is given to all the blasting machines at the same time. A final, synchronised countdown is then started by all blasting machines sending simultaneously, in response to the activating command, a synchronising signal which results in the non-interruptible countdown of the delay time of the detonators starting at a synchronising point which is common to all detonators. If a blasting machine should indicate that a detonator is in an incorrect ready state, or for some other reason is not ready to be fired, abortion of the firing process is allowed according to the present invention, also after the firing command has been given. Alternatively, the firing process may continue if a fault which is identified in a detonator is considered to be of a non-critical kind. It is then possible to choose to continue the firing process in the same way as if nothing incorrect had been found, or continue the firing process according to an alternative procedure, after modification of suitable steps in the firing process. Also using a plurality of blasting machines makes it possible to provide synchronisation of the detonation of the detonators, with maintained flexibility and reliability.

It is thus preferred for one of the blasting machines to be given a primary role and thus act as a main blasting machine while the remaining blasting machines are given a secondary role and thus act as slave blasting machines. The entire combined system is then handled from the main blasting machine while each

slave blasting machine manages the configuration of detonators associated therewith, based on control commands from the main blasting machine. This arrangement makes it possible to control a very large number of detonators from one and the same blasting machine, i.e. the main blasting machine, without necessitating an increase of the signalling voltage to a level which means that the safety of the system is jeopardised, owing to the possibility of limiting the number of detonators per bus. At the same time, firing according to the present invention allows synchronising of all slave blasting machines in a reliable fashion, so that the detonators detonate according to the previously set plan in spite of the fact that they are connected to different blasting machines.

The communication between the main blasting machine and the slave blasting machines occurs preferably by means of radio communication or via a bus in the form of a physical cable. It is also possible to use other types of communication between the main blasting machine and the slave blasting machines, such as different forms of microwave communication, acoustic communication or optical communication using e.g. laser. The choice of way of communication between the main blasting machine and the slave blasting machines is usually dependent on the user's requirements for flexibility and reliability, in relation to costs. It is also conceivable that different national or regional regulations require a certain type of communication.

According to one more aspect of the present invention, test firing of the detonators is allowed, in which these go through all steps leading to detonation, apart from charging of firing power storing means, such as ignition capacitors, and the actual ignition of the explosive charge. The detonators report the result of the test firing to their control unit, whereby a further kind of evaluation of the function of the detonators is allowed. By means of a test firing, it is possible to check

that the detonators have perceived correct delay times, that the receipt of said digital data packets functions in a reliable manner, that said synchronising functions in the intended manner, that countdown of delay times occurs at an expected rate, and that the overall function of the detonators is satisfactory.

The term control unit should, in this description, be considered a generic term for such units as send messages to, and receive responses from, the detonators. Examples of control units is a logging unit, for use when connecting the detonators to the bus and establishing the identity of each detonator, and a blasting machine, for preparing and firing detonators connected to the bus.

The terms logging unit and blasting machine will be explained in more detail in connection with the following description of a preferred embodiment of the invention.

For additional description of characteristic features of an example of a system of the general kind that is intended, reference is made to Swedish Patent Application 9904461-2 which is incorporated herewith by reference.

Brief Description of the Drawings

A preferred embodiment of the invention will be described below with reference to the accompanying drawings, in which

Fig. 1 is an overall view of a number of units included in an electronic detonator system,

Fig. 2 is a schematic view of a control unit with a bus and electronic detonators connected thereto, illustrating how communication with said detonators is accomplished,

Figs 3a and 3b schematically illustrate how a question is asked regarding a predetermined status bit in a predetermined detonator,

Fig. 4 is a flow chart of a general firing process according to the invention,

Figs 5a and 5b are a more detailed flow chart of a firing method according to the present invention,

Fig. 6 schematically illustrates a detonator system with a main blasting machine and a plurality of slave blasting machines, according to the present invention, and

Fig. 7 is a flow chart of a general test firing method according to the present invention.

Description of a Preferred Embodiment

With reference to Fig. 1, a number of units are shown, which are included in an electronic detonator system 1 according to an embodiment of the present invention.

The electronic detonator system 1 comprises a plurality of electronic detonators 10 which are connected to a control unit 11, 12 via a bus 13. The bus 13 serves to communicate signals between the control unit 11, 12 and the detonators 10, i.e. to allow communication therebetween, and to provide power to the detonators 10. The control unit may consist of a logging unit 11 or a blasting machine 12. The detonator system 1 according to the invention may also comprise a portable message receiver 14, which is adapted to be carried by the person connecting the detonators 10 to the bus 13. Via the portable message receiver 14, information is provided regarding, among other things, when the system 1 is ready for connection of one more detonator. Moreover, a computer 15 is preferably included in the system 1, said computer being used to plan the blast. A blasting plan that has been planned in the computer 15 is transferred to one of said control units (logging unit 11 and/or blasting machine 12). Alternatively information collected by the logging unit 11, such as addresses of the electronic detonators 10, can be transferred to the computer 15 for further processing, after which a blasting plan is transferred to

the blasting machine 12 for the final preparation of said detonators 10.

By way of introduction a preferred embodiment of detonator firing according to the present invention will be described with reference to Fig. 2.

A number of detonators 10 are connected to a control unit 12 (blasting machine) by means of a bus 13. The control unit 12 is adapted to send digital data packets 22 to the detonators 10. These data packets 22 communicate instructions and/or questions regarding the state of the detonators 10. The control unit 12 is besides adapted to receive responses 24 from the detonators 10. In the preferred embodiment, the digital data packets 22 consist of 64 bits. In this preferred embodiment, the responses are given by the detonators 10 in the form of analog response pulses 24 on the bus 13. It is preferred for the detonators 10 to give said response pulses 24 in the form of short load pulses detectable by the control unit 12. Such load pulses consist, in a preferred embodiment of the present invention, of a temporary load modulation for the detonator, i.e. the power consumption of the detonator is modulated temporarily. However, it will be appreciated that any influence, detectable by the control unit, on the bus is feasible for this purpose.

As a starting point for the description of a method according to the present invention which is given below, it is assumed that a number of detonators 10 are identified and connected to the bus 13, and corresponding addresses are stored in a blasting machine 12.

A blasting machine is, as mentioned above, the term for the control unit that is used to prepare and fire the detonators 10. The preceding identification of the detonators 10 could be carried out by means of a logging unit 11, which, when connecting detonators 10 to the bus 13, logs addresses etc.

As illustrated in Figs 3a and 3b each detonator 10 comprises a status register 31 which contains a number of

"flags", i.e. information states which can assume either of two possible values, said flags indicating each information state in the detonator 10. Moreover the detonators 10 advantageously have a unique identity which is used to transfer addressed messages to them. The digital data packets 22 which the blasting machine 12 sends on the bus 13 can be globally addressed to all detonators, or be addressed to one or a few detonators. The digital data packets 22 can contain a question regarding the state of a certain flag in the detonator 10, in which case a response is expected from the detonator, or an imperative command to the detonator 10, in which case no response is expected. A response is given by the detonators 10 in the manner indicated above by means of influence, detectable by the blasting machine 12, on the bus, preferably a short load pulse 24.

In the preferred embodiment, said response pulses 24 are only given at a positive response (response in the affirmative) (Fig. 3a) whereas a negative response (response in the negative) appears as the absence of a response pulse (Fig. 3b), which is illustrated in the Figure at 26. Moreover, the appearance of the response 24 from each detonator 10 is identical with the appearance of the response from any other detonator. In the control unit 11, 12, the response pulses 24 are interpreted, which are received from enquiries sent previously (i.e. digital data packets 22 containing a question regarding one or more flags, or status bits, in one or more detonators 10). For each status bit, two enquiries are implemented: a first enquiry asking whether the status bit has the first of two possible values, and a second enquiry asking whether the same status bit has the second of two possible values. By selecting a suitable enquiry, the expected number of response pulses 24 (i.e. the number of detonators giving a response pulse in response to the question) can therefore be minimised, thereby facilitat-

ing the interpretation of the responses in the control unit 11, 12.

With reference to Fig. 4, the function of the electronic detonator system 1 according to the invention will now be described briefly.

A firing command is given (400) by the blasting machine 12. When the firing command has been received by the detonators 10, a flag is set in each detonator which indicates that the firing command is received, and these detonators will consider the receipt of a predetermined data bit in a predetermined data packet (for instance, the first data bit in data packet number 15, counted from the firing command), which follows the firing command, as a synchronising signal (410). In response to the synchronising signal (410), a countdown (411) of a delay time stored in the respective detonators is started. The data packets following the firing command are used for checking (402), (404), (406), (408) that the detonators 10 are ready for detonation.

First it is preferably checked that all detonators have perceived the firing command (401). This is conveniently performed by means of an enquiry (in the form of a digital data packet 22) from the blasting machine 12, said enquiry asking whether there is a detonator 10 which has <u>not</u> perceived the firing command. If no response is received to this question it is assumed that all detonators 10 have perceived the firing command. If a detonator 10 should indicate that it has not received a firing command, the system is reset (420), or switched off, and the entire firing process is repeated from a new start of the system.

When it has been established that all detonators 10 have received and perceived the firing command, a number of questions (402), (404), (406), (408) preferably follow regarding the state of certain flags (i.e. status bits in the status register 31 of the detonators). On the basis of the responses received, the blasting machine 12 deter-

mines whether the firing process should continue. If any fault is found which would seriously jeopardise the impact and/or safety of the blast, the firing process is aborted (430). If the detonators 10 are considered to be in a correct ready state, said synchronising signal is sent (410) from the blasting machine 12. In the preferred embodiment, the synchronising signal consists of the first data bit in data packet number 15, counted from the firing command.

In response to the synchronising signal, each detonator starts said countdown of the corresponding delay time (411). When the countdown of the delay time has been started, it is no longer possible to abort the firing process. When the countdown in each detonator 10 reaches "zero", the detonator 10 is caused to detonate (440).

With reference to Figs 5a and 5b, the firing process will now be described in more detail.

Two sets of delay time information are stored in the blasting machine 12. This information comprises delay times for each connected detonator 10. When starting the system (500), the two sets are checked with regard to each other (510), with the aim of ensuring (511) that correct delay times are stored. Should contradictory information regarding delay times be discovered at this stage, the operation is aborted and new sets of delay times are transferred to the blasting machine (515). If no error is discovered in the delay time information, the delay times are transferred to the respective detonators (520) by individually addressed messages in the form of digital data packets 22.

As an extra measure of precaution, the delay time is preferably transferred twice to each detonator, an error flag being set in the detonator if this does not perceive the same delay time in both transfers (522). When the detonators have received the same delay time twice in a row, a flag is set, indicating that the delay time is received.

When all delay times have been transferred to the respective detonators, the blasting machine suitably checks that no detonator lacks a delay time (not shown). This occurs, for example, by the blasting machine sending a globally addressed enquiry asking whether a detonator has not set the flag indicating that a delay time is received. At this stage it is also possible to check that no detonator has set the error flag.

It should emphasised that if a delay time is transferred a third time, the detonators will set the error flag if not the same delay time as before is involved. A change of a previously transferred delay time must therefore comprise two transfers, with an intermediate reset of the error flag. In this way, the delay times can be changed an optional number of times.

Preferably, it is now checked that ignition capacitor and fuse head are available in each detonator (530) for the risk of duds to be minimised. This is preferably performed by checking a number of flags which indicate when certain voltage levels have been reached in the ignition capacitors of the detonators 10. If an ignition capacitor and/or a fuse head is missing in one or some of the detonators 10, and this is assessed to be a serious error based on previously set criteria, the firing process is aborted (550).

If everything functions so far, it is time to begin charging the ignition capacitor in each detonator. This is performed by an arming command being sent (532) by the blasting machine 12. The arming command is globally addressed, i.e. addressed to all detonators 10, and results in the ignition capacitors beginning to be charged by the voltage of the bus 13. The voltage of the bus 13, however, is still so low that the voltage across the ignition capacitors is kept at a value where there is no risk of ignition of the detonators 10. Before the voltage of the bus 13 is increased to a level where the ignition capacitors begin to be charged to full ignition voltage,

it is suitably checked that no ignition capacitor already indicates that the ignition voltage has been reached (534). Such an indication would indicate an error in the detonator 10, and an assessment should be made whether the detonation process should be aborted (550).

If the detonation process is to be continued, the blasting machine now increases the voltage of the bus 13 (536). The ignition capacitors then begin to be charged to full ignition voltage. A flag in each detonator indicates when full ignition voltage has been reached in the ignition capacitor. During the charging of the ignition capacitors, the blasting machine suitably sends global enquiries, in the form of digital data packets 22, asking whether a detonator 10 has an ignition capacitor that has reached full ignition voltage. When the first detonator answers positively (in the affirmative) to this question, the blasting machine 12 changes to ask the opposite question: if a detonator has an ignition capacitor which has <u>not</u> reached full ignition voltage. When a response (in the affirmative) to this last question is not received any longer, it is assumed that the ignition capacitors of all detonators have reached full ignition voltage (560). In this manner, the charging of the ignition capacitors is verified in the shortest possible time.

Preferably said arming, and the associated charging of the ignition capacitors, occurs by an operator physically pressing an arming button on the blasting machine 12, which arming button must be pressed all the time for the charging of the ignition capacitors to be retained. Firing is suitably initiated by the operator physically pressing a second button, a firing button, while at the same time the arming button is kept pressed. On the blasting machine, a signal (audible or visual) is preferably given (562), which indicates when all ignition capacitors are charged to full ignition voltage, i.e. when the firing button can be pressed.

When the firing button is pressed (564), a firing command is sent (566) on the bus 13 by the blasting machine 12. In the preferred embodiment of the present invention, the firing command differs from all other digital data packets 22 that are sent by the blasting machine 12. The reason for this is that no digital data packets should, by mistake, run the risk of being misinterpreted as a firing command. In fact, the firing command consists of a digital data packet 22 which only consists of a sequence of binary zeros. The condition for a digital data packet 22 to be interpreted as a firing command is that it should at least contain a certain number of binary zeros. Preferably, the counting of the number of zeros is performed in a plurality of independent counters in the detonators 10, a majority decision deciding whether a firing command has been received. If a majority of counters indicate the smallest number of zeros for a firing command, the command is thus interpreted as a firing command.

According to the invention, the countdown of the delay time stored in each detonator is not started immediately after the firing command has been received in the detonators. In the preferred embodiment, it is instead necessary that additional, for instance fourteen, complete data packets be received in the detonators before the final, non-interruptible, countdown starts. This gives, by communication from the blasting machine 12 by means of these additional data packets, the possibility of a last check (570), (572), (574) that each electronic detonator 10 is in the correct state for the desired detonation process to be accomplished. It is to be noted that the contents of these data packets are not important, but that it is the <u>number</u> of data packets that is decisive for the countdown to be started. These data packets could thus have optional contents, contain enquiries or commands or even consist of repeated firing commands.

Should an error be discovered at this stage, there is a possibility of aborting the entire firing process thanks to the fact that said, for instance fourteen, additional data packets must be received before the final countdown is started. This abortion can be provided, for example, by a global resetting command being sent from the control unit or by no further data packets 22 being sent to the detonators 10, which thus do not receive said, for example fourteen, data packets and thus do not start the final countdown. It is preferred for a combination of these abort functions to be used if the firing is to be aborted, i.e. a resetting command first being sent, after which no additional data packets are sent, thereby essentially eliminating the risk of a continued firing process. In case of an aborted firing, the ignition capacitors will gradually be automatically discharged by means of discharge resistors arranged in the detonators 10, so-called bleeder resistors. The number of data packets which must be sent after the firing command for the countdown of the delay time to be started has quite optionally been selected to be fourteen in this example.

The final, non-interruptible, countdown of the delay time thus starts at a synchronising point (580) which is delayed in relation to the firing command and common to all detonators. This synchronising point occurs, in the preferred embodiment of the present invention, when receiving in each detonator a predetermined data bit in a predetermined data packet, which follows the firing command. In the example described above, the synchronisation point occurs at the receipt of a predetermined data bit in data packet number 15, counted from the firing command. However, it is understood that also other types of delayed synchronisation which allows communication with the detonators 10 also after they have received a firing command and thus are in a ready state, are within the scope of the present invention.

From the synchronising point onwards, communication with the detonators is no longer possible. After the synchronising signal the detonators do not require any voltage supply from the blasting machine 12 via the bus 13, but they obtain their necessary voltage supply from a feeding capacitor in each detonator 10. On second thoughts, this is a natural consequence of the fact that the detonation is started since the contact with the blasting machine 12 may at any time be lost owing to a detonation in a detonator.

Thanks to the fact that the detonators, according to the present invention, can be checked when they are in said ready state, the risk of incorrect function after the synchronising point is, however, reduced to a minimum.

When the countdown (585) of the delay time in each detonator reaches "zero", the ignition capacitor is immediately discharged through the fuse head, which results in essentially instantaneous ignition of the explosive charge (590).

The above-mentioned process is also very well suited to be carried out in a system with a main blasting machine 62 and a number of slave blasting machines 64, which is schematically illustrated in Fig. 6. The process is then analogous with that described above, except that the main control of the system 1 occurs from the main blasting machine 62. From the main blasting machine 62, arming, charging, preparation, checking, firing etc. of the detonators 10 are ordered by signalling to the slave blasting machines 64. The slave blasting machines 64 in turn see to it that the functions ordered are carried out for the detonators 10 which are connected to the respective slave blasting machines 64. If applicable, the slave blasting machines 64 report the results of the functions to the main blasting machine 62 which is thus allowed to have the overall control of the entire system 1 without directly needing to communicate with all detonators 10.

A preferred method in a system with main and slave blasting machine as above will now be described.

The main blasting machine 62 is loaded with tables of delay times for the detonators 10 of the respective slave blasting machines 64, said delay times being verified in the same way as described above (510). Each table is transferred to the corresponding slave blasting machine 64 which in turn sees to it that the delay times are transferred (520) to the detonators 10 in the same way as described above. If an error has been found in one of the detonators 10, this is reported by the slave blasting machine 64 of the detonator in question to the main blasting machine 62. A decision whether the process is to be aborted will then be made by the main blasting machine. However, the slave blasting machines 64 can be arranged to make certain decisions which need not be forwarded to the main blasting machine 62. For instance, rules for the conditions under which the entire firing is to be aborted can be implemented in each slave blasting machine 64, in which case such a condition, if any, is communicated back to the main blasting machine, which in turn sees to it that the firing is aborted.

When all slave blasting machines 64 have reported to the main blasting machine 62 that delay times are transferred to the detonators 10, and that everything else is OK, it is indicated on the main blasting machine 62 that the system 1 is ready for arming. The operator then presses the arming button (532) and, in case of OK (562), also the firing button (564), in the same manner as described above. The main blasting machine 62 orders the slave blasting machines 64 to carry out arming and firing, respectively, of detonators associated with the respective slave blasting machines. When each slave blasting machine 64 has reported that the corresponding detonators 10 are ready for detonation (i.e. that the firing command is received, the ignition capacitor is charged, a fuse head is available etc), an activating

command is sent from the main blasting machine 62 to all slave blasting machines 64 at the same time, which slave blasting machines, in response to the activating command, simultaneously give the synchronising signal (508) on the respective buses 13. Thus, synchronisation of all detonators is provided although they are connected to different slave blasting machines 64.

In an alternative embodiment of the present invention, a test firing is carried out before the detonators are armed and fired, which is schematically illustrated by the flow chart in Fig. 7. Such test firing will be described below.

Before the firing process described above is started, it may be desirable to carry out a test firing. The purpose of a test firing can be to check that the detonators 10 have perceived correct delay times, that the receipt of said digital data packets 62 is satisfactory, that said synchronisation (410), (580) functions in the intended manner, that the countdown of delay times (411), (585) occurs at an expected rate, and that the overall function of the detonators is satisfactory.

The test firing is started by the blasting machine 12 sending a test firing command (710) on the bus 13. After receipt of this test firing command in each detonator there is performed, similarly to the actual firing command, a synchronisation (720) which is delayed in relation to the receipt of the test firing command. Optionally, this is preceded by a check (712), (713) of certain flags in the detonators 10, like in the case of the sharp firing. If desired, it is also possible to check that the test firing command has been perceived (711) by all detonators 10 and optionally reset (714) the system 1 and send the test firing command once more. At the synchronising point the countdown of the delay time (730) stored in each detonator is started in the same way as before. When the countdown of the delay time in each detonator reaches "zero", the detonator gives an analog

response pulse 26 (740) on the bus 13. This is the same type of analog response pulse 26 as the one given in the previously described communication between the blasting machine 12 and the detonators 10. The blasting machine 12 detects (750) these response pulses 26 and obtains in this way information about when (i.e. how long after the synchronising point) each detonator will detonate in a coming sharp firing, whereby an evaluation of the test firing is allowed.

It should be pointed out that the test firing is not preceded by arming of the detonators. Thus there is no risk of unintentional firing of a detonator in a test firing since voltage is not applied to the ignition capacitors in the detonators.

If the responses given by the detonators in response to the test firing command should not conform with the expected delay times, first an automatic decision is made whether the entire firing process should be aborted and repeated once more. If the deviation from what is expected is small, an operator may, however, make a decision to let the firing process continue, in which case arming and sharp firing as described above may begin.

Moreover, the test firing can advantageously have a scaling function, through which the stored delay times are multiplied by a scale factor. In the preferred embodiment, the scale factor is 1, 2, 4, 8 or 16. The higher scale factor is selected to be used, the longer it takes to carry out the test firing. The scaling function is a very useful tool for high resolution checking and test of stored delay times as well as the synchronisation of the detonators, particularly when using a plurality of blasting machines.

As described above, the test firing results in the detonators giving an analog response pulse on the bus. In this case, such an analog response pulse is about 2 ms, which means that, without using said scaling function, it is not possible to distinguish two response pulses which

are less than 2-3 ms from each other. It is desirable for the response pulses not be made shorter than said 2 ms since then there is a risk of the detectability in the control unit of these response pulses being reduced to an unacceptably low level. At the same time, however, two instants of detonation can be significantly closer to each other than said 2 ms. By using the scaling function, a high resolution test firing can thus be performed, which gives a resolution which is considerably higher than 2 ms.

It will be appreciated that a test firing of higher resolution (i.e. a test firing using a higher scale factor) will take longer than a test firing of lower resolution. A test firing with the scale factor 8, for instance, takes twice as long as a test firing with the scale factor 4, and therefore it should be taken into consideration whether a high resolution is really necessary or if preference is given to a quick firing process.

In conformity with that described above in connection with the firing process, also the test firing can be carried out in a system having a main blasting machine and slave blasting machines. Each slave blasting machine reports the time distribution of the responses from the detonators to the main blasting machine, which in turn evaluates the result of the test firing. In fact, test firing is most desirable, especially when a system with slave blasting machines is used since it is then allowed via the main blasting machine to check that the synchronisation of all slave blasting machines and the detonators connected thereto functions in the intended manner. At the same time the main blasting machine receives information whether correct delay times are stored in the detonators, and whether the countdown rate of these delay times is correct.

The invention has been described above on the basis of a preferred embodiment. However, this description does not aim at restricting the scope of the invention in any

sense. It will be appreciated that modifications can by made within the scope of the invention, as defined in the appended claims.

CLAIMS

1. A method for firing electronic detonators included in an electronic detonator system, said detonator system comprising a control unit and a bus, the electronic detonators being connected to the control unit via said bus and communication between the control unit and the electronic detonators occurring on the bus, said method comprising the steps of

sending a firing command from the control unit on the bus,

receiving said firing command in said electronic detonators,

setting, in response to said received firing command, the electronic detonators in a ready state,

awaiting a synchronising signal, which is delayed in relation to the firing command and which is sent by the control unit and indicates a synchronising point which is common to said detonators, the synchronising point preferably being the time of receiving said synchronising signal,

sending a synchronising signal from the control unit on the bus,

starting, at the synchronising point, countdown in each electronic detonator of a delay time stored therein, and

causing, on completion of said countdown, each detonator to detonate.

2. A method as claimed in claim 1, wherein communication from the control unit to the electronic detonators is performed by means of digital data packets and wherein communication from the electronic detonators to the control unit is preferably performed by influence, detectable by the control unit, on the bus, particularly analog load pulses.

3. A method as claimed in claim 2, wherein the step of awaiting said delayed synchronising signal comprises the step of receiving in the detonators a predetermined number of digital data packets, whereupon the detonators are in a state that allows receipt of a synchronising signal, the synchronising signal preferably being the subsequent digital data packet.

4. A method as claimed in any one of the preceding claims, wherein the synchronising point is the time of receiving in each detonator a predetermined data bit in a predetermined data packet, which is sent by the control unit after said firing command has been sent.

5. A method as claimed in any one of the preceding claims, wherein the control unit, subsequent to the firing command and prior to the synchronising point, sends a predetermined number of data packets, whereby communication with, and thus control and checking of, the detonators is allowed after they have received said firing command and thus are in said ready state.

6. A method as claimed in any one of the preceding claims, wherein a check that each detonator has received the firing command is performed before the synchronising signal is sent on the bus.

7. A method as claimed in any one of the preceding claims, wherein a check that no detonator has an error indicator is performed before the synchronising signal is sent on the bus.

8. A method as claimed in any one of claims 2-7, wherein at least one of the data packets that are not used for communication with the detonators comprises a further firing command.

9. A method as claimed in any one of the preceding claims, wherein all data bits in said firing command, comprising also overhead bits if any, are identical and preferably consist of binary zeros.

10. A method for firing electronic detonators included in an electronic detonator system, said detonator system comprising a main control unit, at least one slave control unit and a bus, the electronic detonators being connected to said slave control unit via said bus and communication between the slave control unit and the electronic detonators being performed on the bus, said method comprising the steps of

ordering, by means of the main control unit, the slave control unit to send a firing command on the bus,

receiving said firing command in said electronic detonators,

setting, in response to said received firing command, the electronic detonators in a ready state,

awaiting a synchronising signal which is delayed in relation to the firing command and which is sent by the slave control unit and indicates a synchronising point which is common to said detonators, the synchronising point preferably being the time of receiving said synchronising signal,

sending a synchronising signal from the slave control unit on the bus,

starting, at the synchronising point, countdown in each electronic detonator of a delay time stored therein, and

causing, on completion of said countdown, each detonator to detonate.

11. A method as claimed in claim 10, wherein the slave control unit's sending of the synchronising signal is performed at the command of the main control unit,

whereby a plurality of slave control units are allowed to simultaneously send synchronising signals.

12. A method as claimed in claim 10 or 11, wherein communication from the control unit to the electronic detonators is performed by means of digital data packets and communication from the electronic detonators to the slave control unit is preferably performed by influence, detectable by the slave control unit, on the bus, particularly analog load pulses.

13. A method as claimed in claim 12, wherein the step of awaiting said delayed synchronising signal comprises the step of receiving in the detonators a predetermined number of digital data packets, whereupon the detonators are in a state which allows receipt of a synchronising signal, the synchronising signal preferably being the subsequent digital data packet.

14. A method as claimed in any one of claims 10-13, wherein the synchronising point is the time of receiving in each detonator a predetermined data bit in a predetermined data packet, which is sent by the slave control unit after said firing command has been sent.

15. A method as claimed in any one of claims 10-14, wherein the slave control unit, subsequent to the firing command and prior to the synchronising point, sends a predetermined number of data packets, whereby communication with, and thus control and checking of, the detonators is allowed after they have received said firing command and thus are in said ready state.

16. A method as claimed in any one of claims 10-15, wherein communication between the main control unit and the slave control unit is performed by means of radio communication.

17. A method as claimed in any one of claims 10-15, wherein communication between the main control unit and the slave control unit is performed via a bus in the form of a physical cable.

18. A method as claimed in any one of claims 10-17, wherein a check that each detonator has received the firing command is performed before the synchronising signal is sent on the bus.

19. A method as claimed in any one of claims 10-18, wherein a check that no detonator has an error indicator is performed before the synchronising signal is sent on the bus.

20. A method as claimed in any one of claims 10-19, wherein at least one of the data packets that are not used for communication with the detonators comprises a further firing command.

21. A method as claimed in any one of claims 10-20, wherein all data bits in said firing command, comprising also overhead bits if any, are identical, and preferably consist of binary zeros.

22. A method for firing electronic detonators included in an electronic detonator system, said detonator system comprising a control unit and a bus, the electronic detonators being connected to the control unit via said bus and communication between the control unit and the electronic detonators being performed on the bus, said method comprising the steps of

sending a test firing command from the control unit on the bus,

receiving said test firing command in said electronic detonators,

awaiting a synchronising signal which is delayed in relation to the test firing command and which is sent by the control unit and indicates a synchronising point which is common to said detonators, the synchronising point preferably being the time of receiving said synchronising signal,

sending a synchronising signal from the control unit on the bus,

starting, at the synchronising point, countdown in each electronic detonator of a delay time stored therein,

giving, on completion of said countdown, a response from each detonator,

receiving said response in the control unit, and

on the basis of these responses, especially the time distribution thereof, making an evaluation of the electronic detonator system.

23. A method as claimed in claim 22, wherein communication from the control unit to the electronic detonators is performed by means of digital data packets and communication from the electronic detonators to the control unit is preferably performed by means of influence, detectable by the control unit, on the bus, particularly analog load pulses.

24. A method as claimed in claim 22 or 23, wherein the step of awaiting said delayed synchronising signal comprises the step of receiving in the detonators a predetermined number of digital data packets, whereupon the detonators are in a state that allows receipt of a synchronising signal, the synchronising signal preferably being the subsequent digital data packet.

25. A method as claimed in any one of claims 22-24, wherein the synchronising point is the time of receiving in each detonator a predetermined data bit in a predeter-

mined data packet, which is sent by the control unit after said test firing command has been sent.

26. A method as claimed in any one of claims 22-25, wherein the test firing command indicates a scale factor, by which the delay time stored in each detonator is multiplied before said countdown thereof is started, whereby a high-resolution test firing is provided.

27. A method for firing electronic detonators included in an electronic detonator system, said detonator system comprising a main control unit, at least one slave control unit and a bus, the electronic detonators being connected to said slave control unit via said bus and communication between the slave control unit and the electronic detonators being performed on the bus, said method comprising the steps of

commanding, by means of the main control unit, the slave control unit to send a test firing command on the bus,

receiving the test firing command in said electronic detonators,

awaiting a synchronising signal which is delayed in relation to the test firing command and which is sent by the slave control unit and indicates a synchronising point which is common to said detonators, the synchronising point preferably being the time of receiving said synchronising signal,

sending a synchronising signal from the slave control unit on the bus,

starting at the synchronising point countdown in each electronic detonator of a delay time stored therein,

giving, on completion of said countdown, a response from each detonator,

receiving said response in the slave control unit, and

on the basis of these responses, especially the time distribution thereof, making an evaluation of the electronic detonator system.

28. A method as claimed in claim 27, wherein the slave control unit's sending of the synchronising signal is performed at the command of the main control unit, whereby a plurality of slave control units are allowed to simultaneously give synchronising signals.

29. A method as claimed claim 27 or 28, wherein communication from the slave control unit to the electronic detonators is performed by means of digital data packets and communication from the electronic detonators to the slave control unit is preferably performed by influence, detectable by the slave control unit, on the bus, particularly analog load pulses.

30. A method as claimed in any one of claims 27-29, wherein the step of awaiting said delayed synchronising signal comprises the steps of receiving in the detonators a predetermined number of digital data packets, whereupon the detonators are in a state which allows receipt of a synchronising signal, the synchronising signal preferably being the subsequent digital data packet.

31. A method as claimed in any one of claims 27-30, wherein the synchronising point is the time of receiving in each detonator a predetermined data bit in a predetermined data packet, which is sent by the slave control unit after said test firing command has been sent.

32. A method as claimed in any one of claims 28-31, wherein the test firing command indicates a scale factor, by which the delay time stored in each detonator is multiplied before said countdown thereof is started, whereby a high resolution test firing is provided.

33. An electronic detonator system, comprising a control unit, a plurality of electronic detonators and a bus, which connects said detonators to the control unit, the detonators being controllable and checkable by means of digital data packets which are sent on the bus from the control unit, and are adapted to detonate after a delay time established for each detonator has elapsed from a synchronising point which is common to all detonators, in response to a firing command sent from the control unit, characterised in that said synchronising point occurs after said firing command has been received by said detonators, and the control unit is adapted to communicate with the detonators also after these have received the firing command and, in any case, up to the synchronising point.

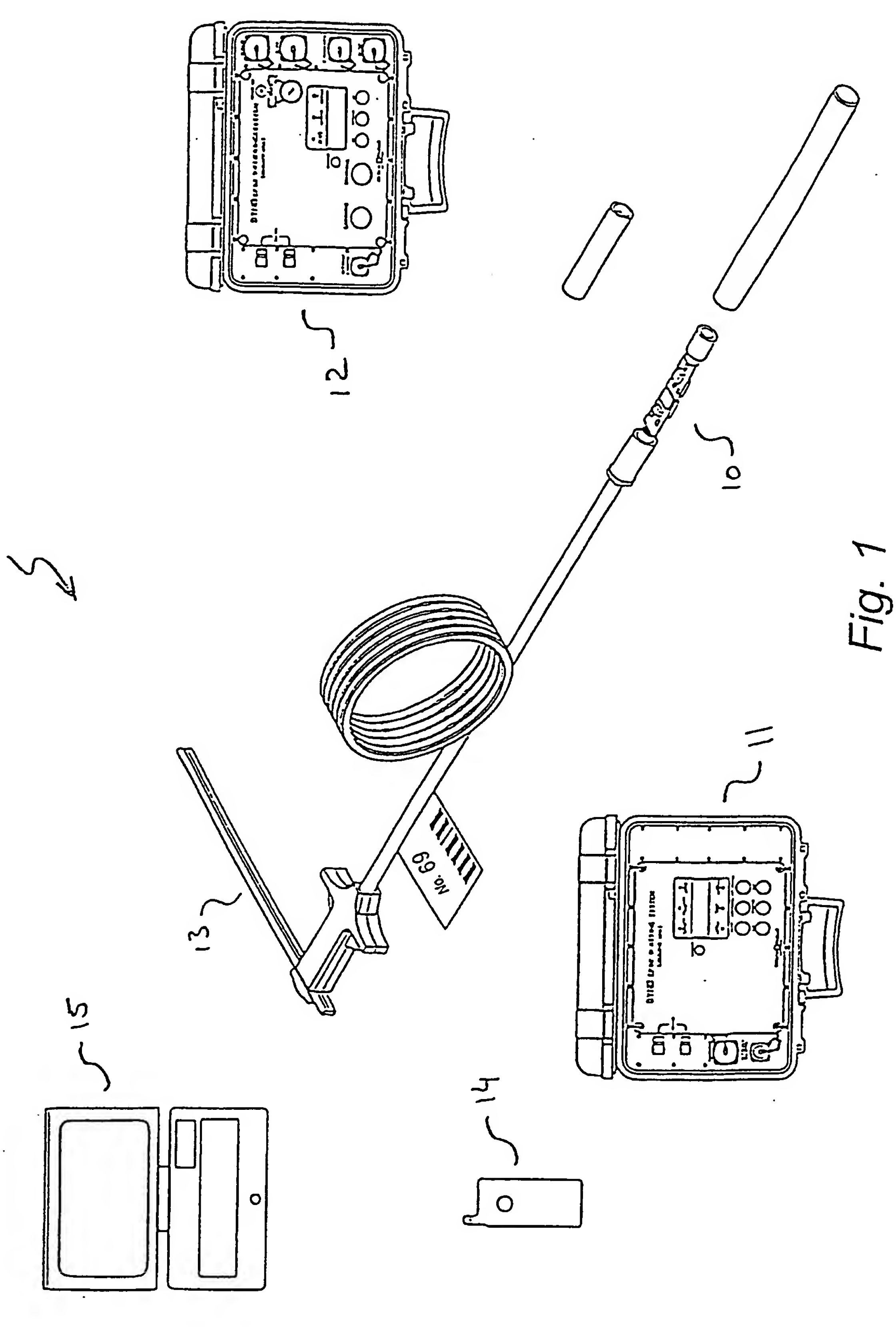


Fig. 1

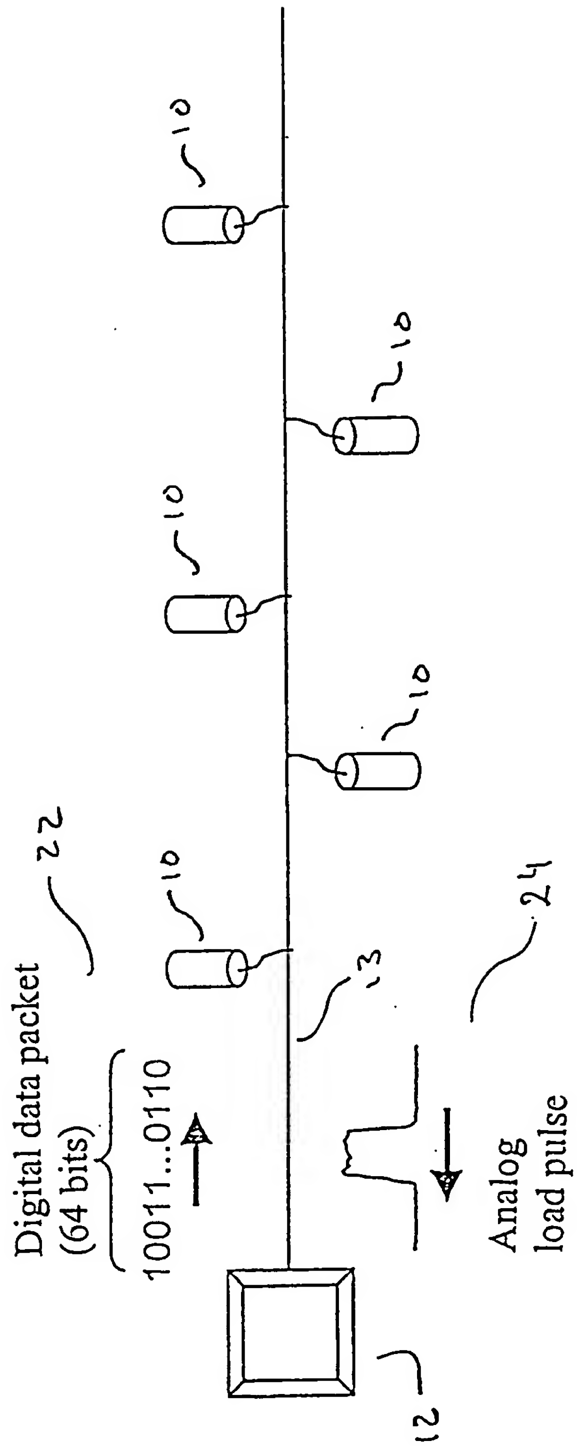

Digital data packet
(64 bits)
10011...0110
Analog
load pulse
10
10
10
10
10
22
13
24
12

Fig. 2

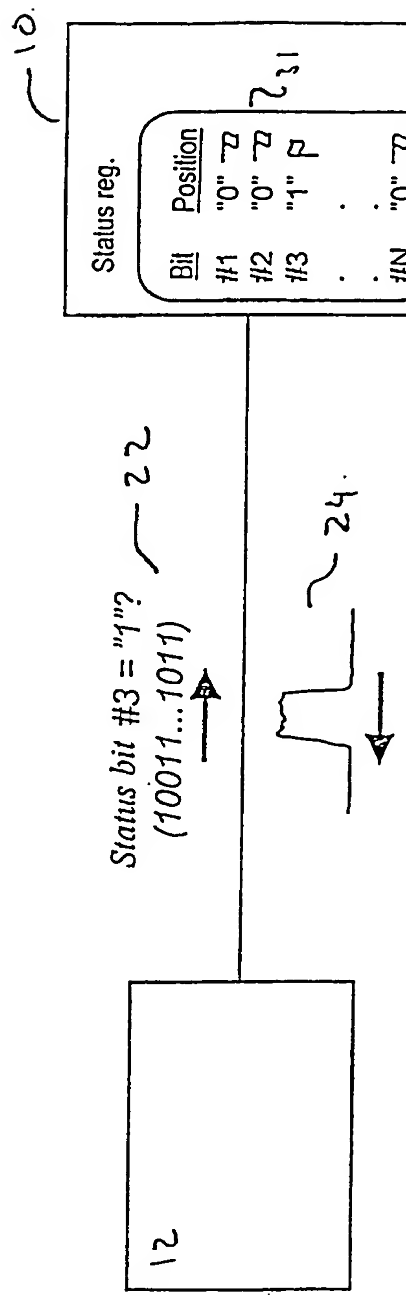

10
Status reg.
Bit Position
#1 "0" p
#2 "0" p
#3 "1" p
#N "0" p
31
Status bit #3 = "1"?
(10011...1011)
22
24
"Yes"
12

Fig. 3a

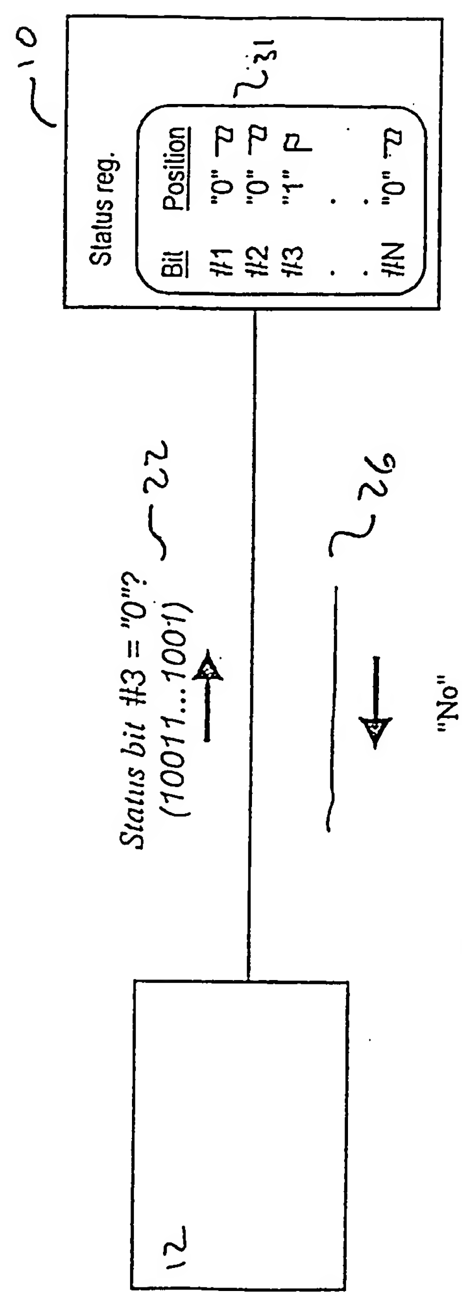

10
Status reg.
Bit Position
#1 "0" p
#2 "0" p
#3 "1" p
#N "0" p
31
Status bit #3 = "0"?
(10011...1001)
22
26
"No"
12

Fig. 3b

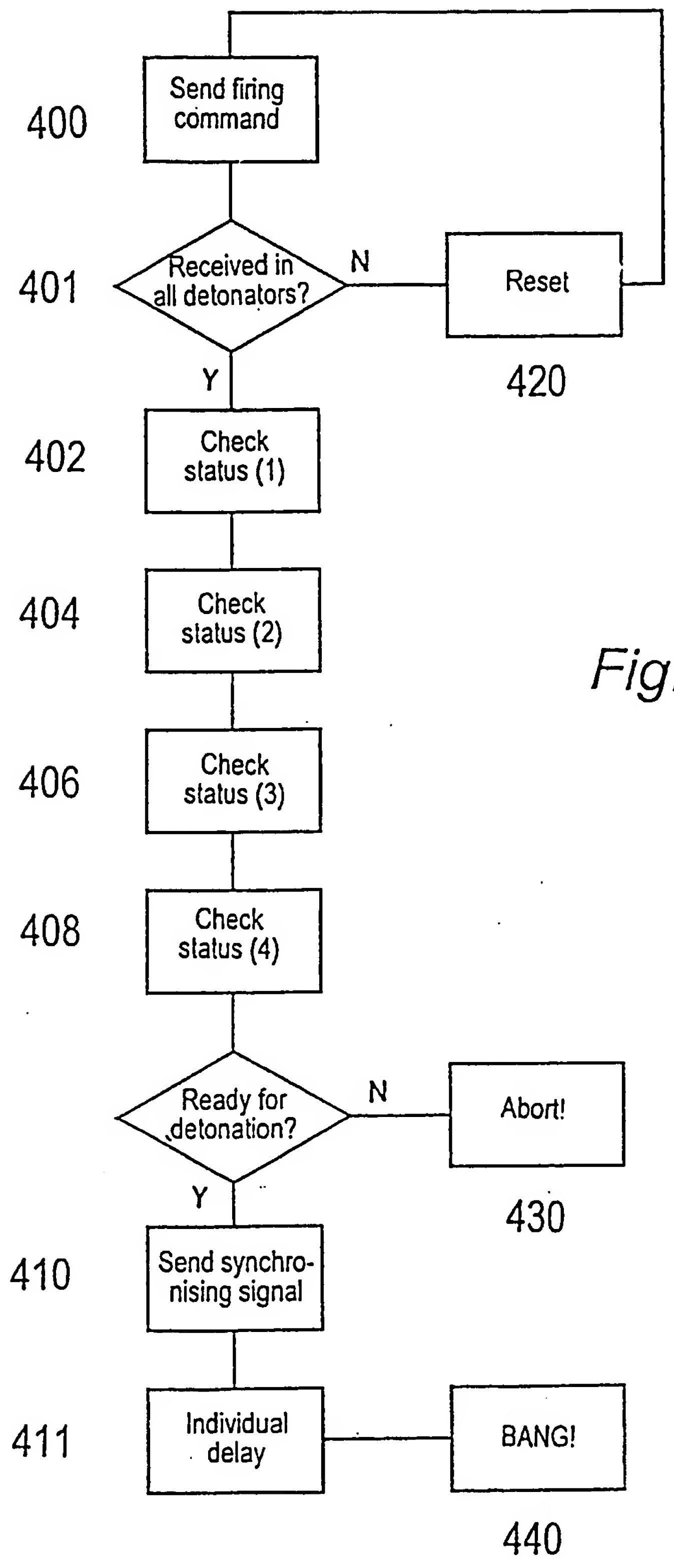

Send firing command
400
Received in all detonators?
401
N
Reset
420
Y
Check status (1)
402
Check status (2)
404
Check status (3)
406
Check status (4)
408
Ready for detonation?
N
Abort!
430
Y
Send synchro-nising signal
410
Individual delay
411
BANG!
440

Fig. 4

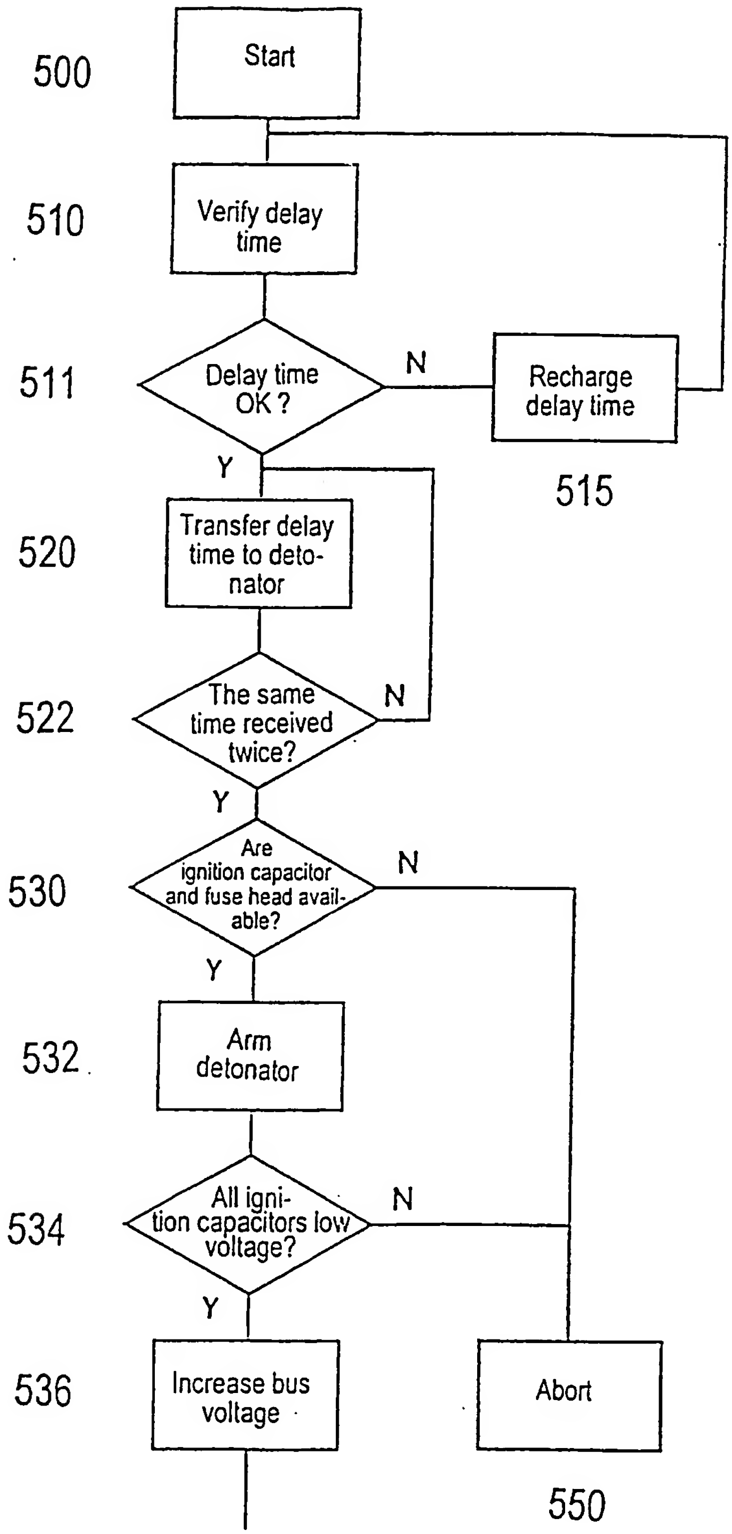


Fig. 5a

to Fig. 5b

from Fig. 5a

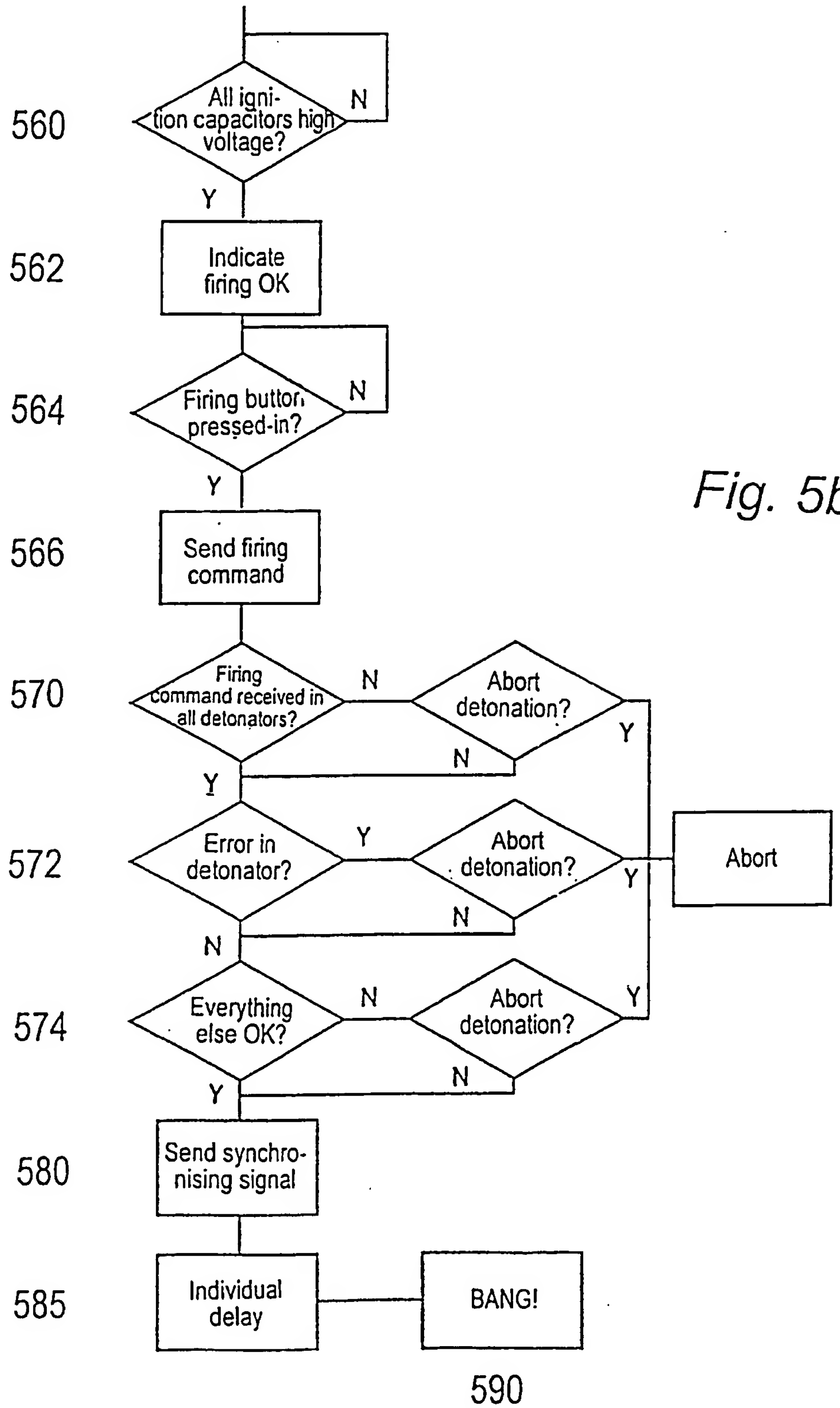


Fig. 5b

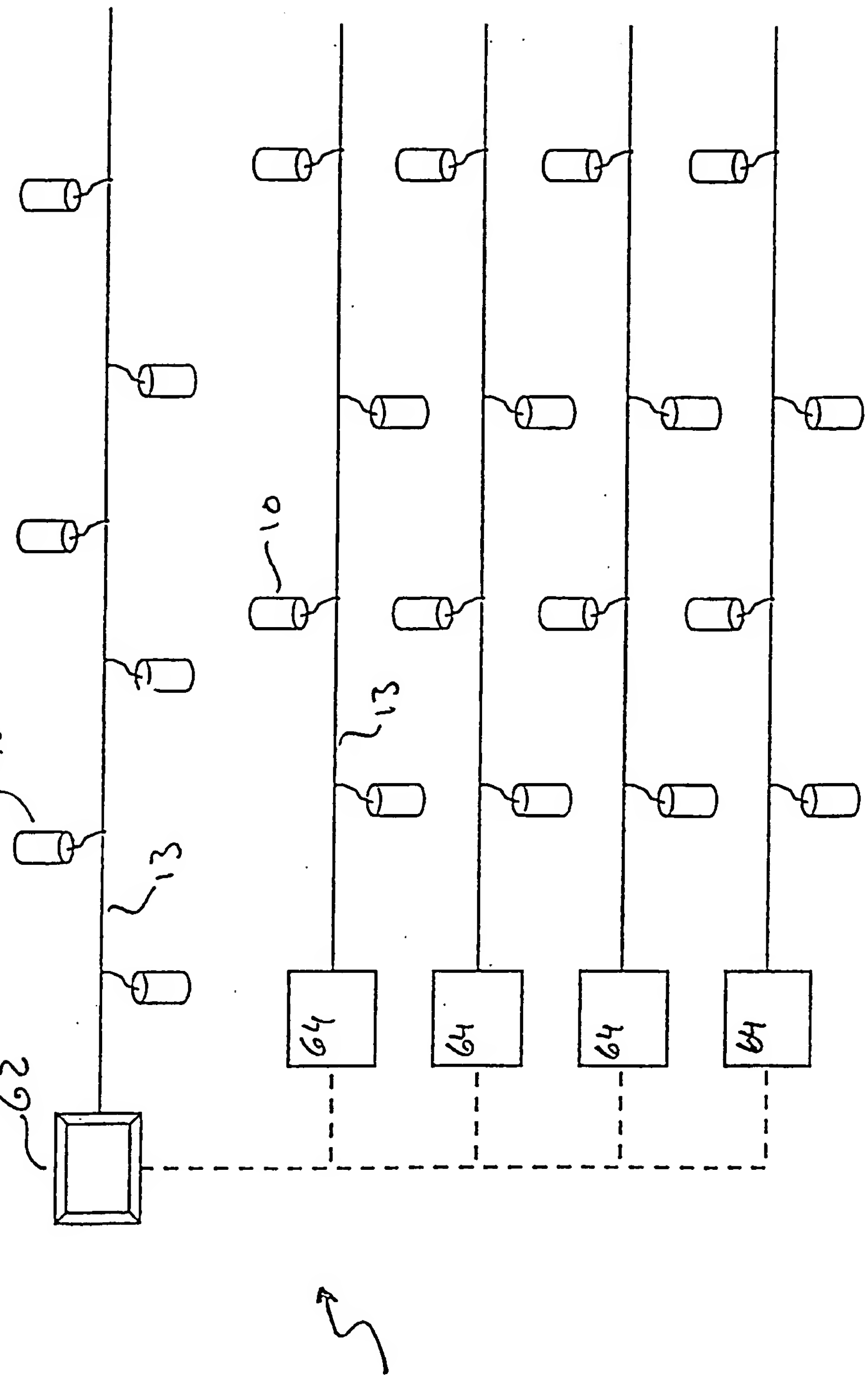
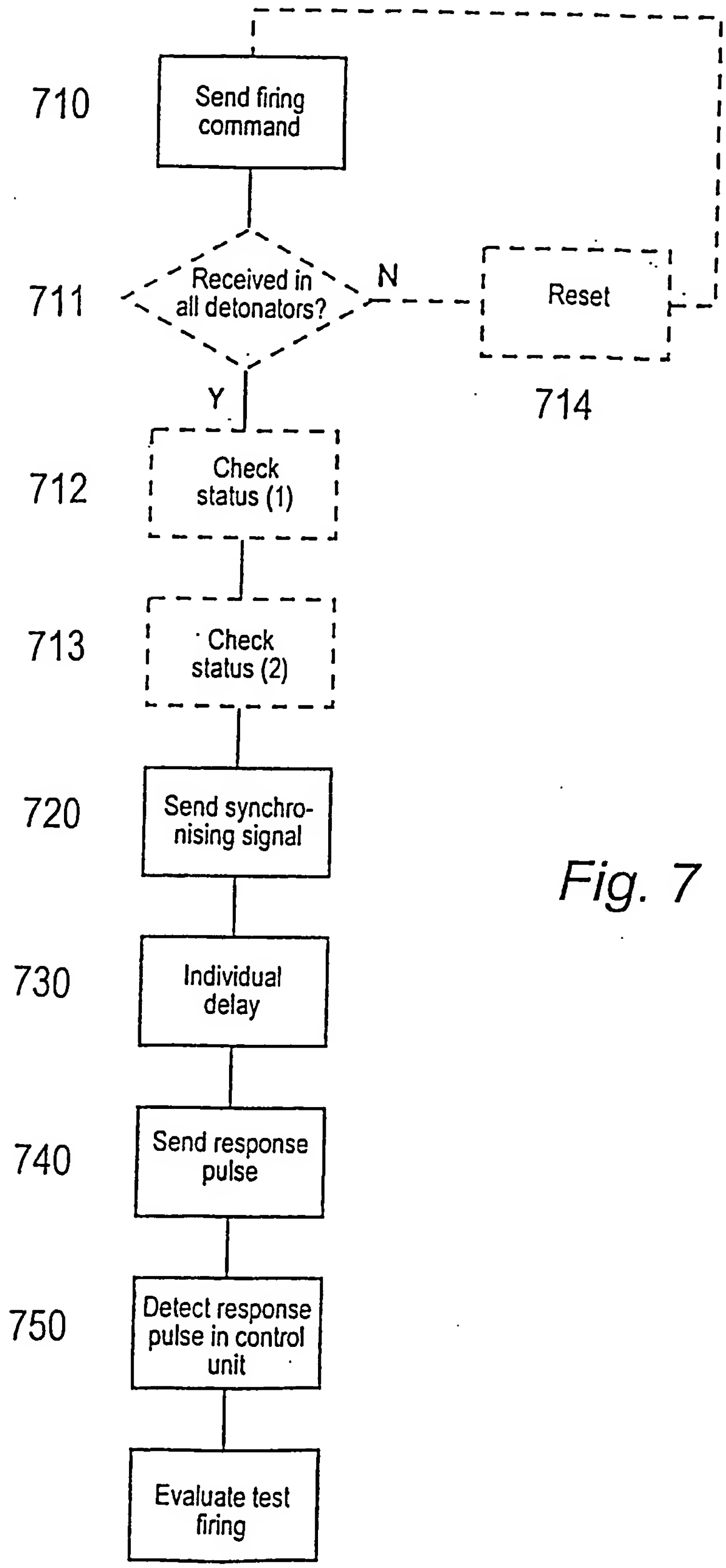


Fig. 6



710
Send firing command
711
Received in all detonators?
N
Reset
714
Y
712
Check status (1)
713
Check status (2)
720
Send synchro-nising signal
730
Individual delay
740
Send response pulse
750
Detect response pulse in control unit
Evaluate test firing

Fig. 7

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 01/00507

A. CLASSIFICATION OF SUBJECT MATTER

IPC7: F42D 1/055
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC7: F42D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

QUESTEL: EDOC, WPIL, JAPIO

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5539636 A (MICHAEL J.C. MARSH ET AL), 23 July 1996 (23.07.96), column 3, line 51 - column 5, line 42, figures 1,2a,2b, claim 1 --	1,10,22,27, 33
A	US 4674047 A (LAWSON J. TYLER ET AL), 16 June 1987 (16.06.87), column 5, line 22 - line 47 --	1-33
A	US 5406890 A (MICHAEL J.C. MARSH ET AL), 18 April 1995 (18.04.95), claims 1-3 --	1-33
A	US 4537131 A (PETER J. SAUNDERS), 27 August 1985 (27.08.85), claim 1 --	1-33

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
29 May 2001	01 -06- 2001
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Bengt Christensson/MP Telephone No. +46 8 782 25 00

INTERNATIONAL SEARCH REPORT
Information on patent family members

30/04/01

International application No.
PCT/SE 01/00507

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5539636 A	23/07/96	AT 159100 T	15/10/97
		AU 672835 B	17/10/96
		AU 5222793 A	16/06/94
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		AT 132250 T	15/01/96
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		AU 657217 B	02/03/95
		AU 3846493 A	15/07/93
		AU 6324490 A	11/04/91
		CA 2026220 A,C	29/03/91
		DE 69024446 D,T	13/06/96
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		EP 0096482 A,B	21/12/83
		SE 0096482 T3	
		ES 522920 A	16/11/84
		ES 8501523 A	16/02/85
		FI 72600 B,C	27/02/87
		FI 831836 A	04/12/83
		GB 2121089 A,B	14/12/83
		GB 8313423 D	00/00/00
		HK 59186 A	22/08/86
		IN 159564 A	23/05/87
		JP 59027200 A	13/02/84
		NO 831831 A	05/12/83
		NZ 204354 A	14/03/86
		PH 19900 A	13/08/86
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